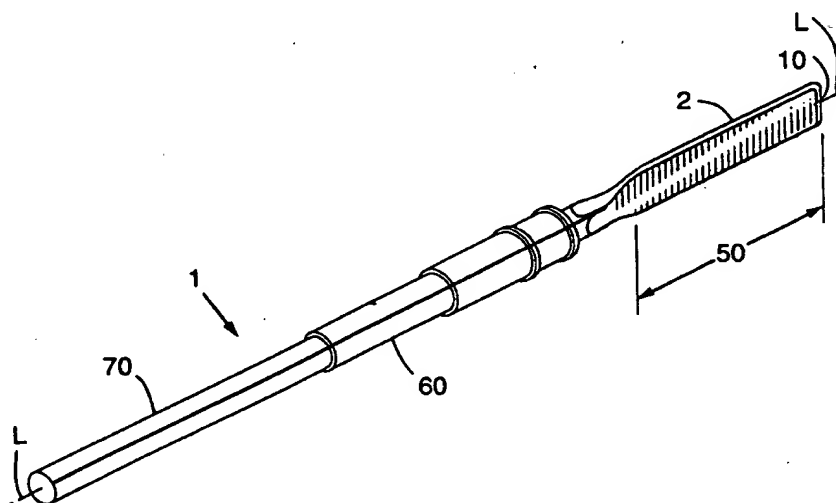




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(54) Title: ELECTROSURGICAL BLADE CONFIGURED FOR IMPROVED CUTTING EASE AND REDUCED SMOKE GENERATION AND ESCHAR ADHESION



## (57) Abstract

This invention is a monopolar electro-surgical instrument (1) having a blade (2) with an electrically conductive active electrode surface configured to improve cutting or cauterizing efficiency, and a blade for use in such instrument. In use, current (typically RF current) flows from the active electrode surface directly into patient tissue. In preferred embodiments, the blade's active electrode surface includes one or more conductive working edges shaped to focus energy from a current source so that the energy causes efficient cutting or cauterization of tissue adjacent to each working edge. Preferably, the blade's cross section satisfies at least one of the following criteria: a working edge having an edge angle of at least 50 degrees, an aspect ratio (of major to minor axis) greater than four (in embodiments with elliptical cross section), and a ratio of truncated working edge width to minor axis less than 1/3 (in embodiments with a truncated, beveled working edge).

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# ELECTROSURGICAL BLADE CONFIGURED FOR IMPROVED CUTTING EASE AND REDUCED SMOKE GENERATION AND ESCHAR ADHESION

## Cross-reference to Related Application

5 The present application is a continuation-in-part of pending U.S. Patent Application 08/661,980, filed June 12, 1996.

## Field of the Invention

10 The invention relates generally to instruments for use in electrosurgical procedures. More specifically, the invention relates to a monopolar electrosurgical instrument having a blade configured to improve cutting ease and reduce smoke generation and tissue adhesion during use.

## Background of the Invention

15 Electrosurgery has become an important alternative to conventional surgical techniques and offers many advantages over the traditional procedures. In electrosurgery, an electric current is used to cut or cauterize human or animal tissue.  
20 Electrosurgical instruments pass RF current (current whose amplitude varies periodically at radio frequency) through tissue to cause resistive heating of the tissue. During cutting operations, the current passed through the tissue causes water to  
25 vaporize and expand rapidly, causing gentle tearing or opening of the tissue structure. During coagulation operations, the current passed through the tissue simply heats the tissue.

30 The expression "electrosurgical instrument" is not used herein to denote an instrument which relies on resistive heating of a non-conducting blade (a blade made of electrically insulating material) to

provide thermal energy for enhanced cutting and/or cauterization. Examples of instruments which rely on such resistive heating of non-conducting blades are those described in U.S. Patent 4,219,025 to Johnson and in U.S. Patent 4,231,371 to Lipp.

There are two main types of electrosurgical instruments in use. Depending on the number of electrodes used in the cutting and cauterization they are called bipolar or monopolar instruments. The term "unipolar" is used as a synonym for "monopolar."

In a monopolar electrosurgical instrument, RF current is supplied to a single electrode which is used to cut and/or cauterize tissue. When in use, electric current flows from the instrument's single electrode to the patient, and the electric circuit is completed using a "patient plate electrode" affixed to the patient's skin (a periodically varying potential difference, typically having radio frequency, is maintained between the electrode and patient plate). The surface area of the electrode through which current flows (the "active electrode surface") is small relative to the area of the patient plate and therefore an intense local current density is generated at the electrode. This results in cutting or cauterization of the tissue in the immediate proximity of the electrode. An example of a monopolar electrosurgical instrument is described in U.S. Patent No. 4,927,420 (discussed below).

In contrast, a bipolar electrosurgical instrument has two electrodes. A potential difference (typically a periodically varying potential difference) is maintained between the electrodes during use. No "patient plate" is used, as with a monopolar apparatus. The two electrodes of a bipolar instrument are separated by a small gap

(typically on the order of a few millimeters or less). In operation, an intense local current density is generated between the electrodes and this results in cutting or cauterization of the tissue adjacent to the gap between the electrodes. Examples of bipolar electrosurgical instruments are described in U.S. Patents No. 4,850,353, 4,862,890, 4,958,539, 5,071,419, 5,396,900, 5,217,458, 5,342,381, and 5,395,369.

For example, U.S. Patent 4,862,890, to Stasz, et al. describes a bipolar instrument whose electrodes are thin metal regions on an insulating substrate. In some embodiments, a glass-like insulating overcoat is applied over the substrate and one or more metal patterns on the substrate, and the overcoat is then ground away to expose two strips of metal and an insulating gap (comprising exposed substrate) between the metal strips. U.S. 4,862,890 teaches that the gap width should be on the order of 0.003 inch, for the stated reason that if the gap is larger, too high a voltage is needed to create an arc between the metal strips, and if the gap is smaller, sufficiently high RF energy cannot be maintained to cut tissue. U.S. 4,862,890 teaches that the blade should have parallel main surfaces above and below the gap (with the gap surface perpendicular to both main surfaces), and a beveled surface (oriented at an angle of 70 degrees relative to the gap surface) between the gap and each main surface.

The electrodes used in both monopolar and bipolar instruments come in a wide variety of shapes, sizes, and configurations. Depending on the surgical requirements, the electrodes can be in any of a variety of shapes such as needles, loops, spatulas, scalpel blades, scissors, forceps, and balls.

Electrosurgical instruments have been extensively used for endoscopic surgery. Since electrosurgical tools can both cut and cauterize tissue, electrosurgery is especially suited to endoscopic surgery. A wide variety of shapes and configurations of endoscopic electrodes have been described. See for example U.S. Patents No. 5,396,900, 5,217,458, and 5,395,369.

One type of conventional electrosurgical instrument, known as a Bovie blade, comprises a flat blade made of electrically conducting material. Typically, the blade is about 1 inch long, 0.1 inch wide, and 0.02 inch thick. The blade is held in an electrosurgical pencil which has a switch for controlling current flow. The pencil is connected by a wire to a power supply configured to produce a specified current and voltage at a desired frequency for either cutting or cauterization. In use, a high electric current density is generated between the electrodes and tissue causing intense heating which carburizes the tissue and results in the required cutting or cauterization.

In conventional electrosurgical instruments, the active electrode surface is usually made of metal such as stainless steel ("SS"). However, there is a well known drawback to using SS electrodes: burnt tissue tends to adhere to the electrode surface during the electrosurgical procedure.

This burnt tissue, called "eschar," builds up on the electrode surfaces, reducing cutting and cauterization efficiency. When this buildup is thick enough to reduce the instrument's efficacy, the surgeon is forced to stop the operation and clean the electrosurgical instrument. This cleaning can require enough force to scratch the surface of the

SS. Such scratches roughen the surfaces of the instrument which in turn causes tissue residue to build up faster and requiring even more frequent cleaning.

5           During cauterization the blade can stick to the tissue and reopen the cauterized blood vessels when pulled away by the surgeon.

          Many attempts have been made to overcome the problem of tissue buildup and adhesion in  
10       conventional electrosurgical apparatus. For example, metal electrodes have been coated with an organic material, usually a Teflon material or other polymer. For example, U.S. Patent 4,785,807 discloses coating an electrosurgical blade with polytetrafluoroethylene  
15       (PTFE). Unfortunately, such coating materials cannot withstand the high localized temperatures of the electric discharge between the electrode surface and the tissue. The coating materials often burn off, melt off, or scrape off the substrate during use.  
20       The coatings, and the resulting products of the burnt or vaporized coating materials, are known to form harmful chemical products which may be deposited into the cut/cauterized wounds. It has also been reported that after exposure to vaporized organic coating  
25       materials during electrosurgery, personnel may have flu-like symptoms result (this problem has been termed "polymer fume fever"). A further disadvantage is that at high power settings on the electrosurgical generator, a coating of organic material can be  
30       destroyed or stripped off in the very early stages of the electric discharge and therefore provides little or no improvement in the reduction of tissue adhesion from the electrode to the tissue.

          Polymer coatings, being electrically insulating  
35       materials, on electrosurgical instrument blades

inhibit the flow of electrons between the tissue and blade. Thus, in instruments having such coatings, the coatings must either be porous, or must be ground away in places to expose bare electrically conductive material, or must include electrically conductive filler materials. It is well known that many polymer coated blades do not cut well until the coating has burned off the edge of the blade. Alternatively, some electrically insulating coatings must be sufficiently thin that adequate RF energy can be capacitively coupled through the coating from the blade into the tissue.

For example, U.S. Patent 5,697,926 discloses an electrosurgical instrument comprising an electrically conductive metal blade and a thin diamond coating on the blade. The diamond coating is electrically insulating, but is deposited as a layer that is sufficiently thin so that adequate RF electrical energy is capacitively coupled from the blade through the coating into the patient. When relying on capacitive coupling, there are strict limits on the maximum thickness of the insulating material exposed to the patient, since no cutting or cauterizing can occur if the insulating material is too thick.

Above-cited U.S. Patent 4,862,890 suggests applying a glass-like dielectric overcoat over both the substrate and one or more metal patterns on the substrate of a bipolar instrument to reduce adherence of tissue to the instrument. However, a portion of the overcoating is ground away to expose bare metal electrode material. Thus the exposed metal electrodes are subject to the above-noted problem of tissue adhesion.

Another proposed solution to the problem of tissue adhesion is the use of a vibrating blade.

Such a solution is disclosed in U.S. Patents No. 4,674,498, 4,802,476, and 4,922,903. Each of these references describes an electrosurgical apparatus with an electrosurgical blade that vibrates during  
5 use to prevent buildup of tissue and debris on the blade. The vibration technique requires that the apparatus include a means for vibrating and a means for coupling the vibrations to the electrosurgical instrument. This increases the cost and complexity of  
10 the apparatus and in some cases, for instance endoscopic surgery, may present great technological problems.

U.S. Patent No. 4,927,420, to Newkirk et al., describes a monopolar electrosurgical instrument  
15 comprising an ultrasharp metal needle electrode whose size and shape are said to allow use of lower RF power (due to high concentration of RF energy at the needle tip), and thus to reduce blood loss, scarring and drag (tissue buildup) when cutting tissue. The  
20 needle electrode has a circular cross-section with a distal end diameter of less than 50 microns (preferably less than 10 microns) and a proximal end diameter of less than 0.05 inch (0.02 inch in some embodiments), and is composed of any of a variety of  
25 refractory metal alloys. However, the elimination of drag in using such a needle relies on being able to use reduced RF power which in turn relies on the use of an instrument having the described ultrasharp needle shape and size. Thus the teaching of U.S.  
30 4,927,420 is severely limited in the range of shapes and sizes of electrosurgical instruments to which it may be applied.

Another problem with electrosurgery is the generation of smoke, as a result of heating tissue  
35 which in turn forms eschar. The smoke can carry

infectious agents that can affect operating room personnel. The practice of collecting and filtering smoke during electrosurgery has existed for a long time. Recent findings have emphasized the need to  
5 minimize smoke generation during electrosurgery, and to evacuate that smoke which is generated. Conventional electrosurgical blades, which are subject to the above-described tissue buildup problem, are also subject to the smoke generation  
10 problem.

From the foregoing discussion it is apparent that there exist basic problems in electrosurgery: namely, the buildup of tissue (eschar) on electrosurgical instruments, and generation of smoke  
15 during electrosurgical procedures. Although some solutions to the problem of tissue buildup have been proposed, they all have limitations and drawbacks. There is a need for electrosurgical instruments to which tissue does not adhere (without the need to  
20 couple each instrument to an external mechanical vibrating means), which do not generate an undesirable amount of smoke during use, and which can be formed in a variety of useful shapes and sizes.

#### Summary of the Invention

25 In a class of embodiments, the invention is a monopolar electrosurgical instrument comprising a blade having an electrically conductive active electrode surface which focuses electrical energy and reduces eschar adhesion. In use the blade is coupled  
30 to a source of current (typically having frequency in the RF range) to cause current to flow from the active electrode surface through patient tissue to a remote electrode (e.g., to a patient plate). The blade's active electrode surface includes one or more

electrically conductive working edges shaped to focus energy from the current source (typically RF energy) so that the energy causes efficient cutting or cauterization of tissue adjacent to each working edge. In preferred embodiments, the blade has a cross-section which satisfies at least one of the following shape criteria: a working edge (which can be a sharp working edge) having an edge angle of at least 50 degrees; an aspect ratio (the ratio of major axis to minor axis) greater than four (in embodiments in which the cross-section is elliptical or approximately elliptical); and a ratio of truncated working edge width to minor axis less than  $1/3$  (in embodiments in which the blade has a truncated, beveled working edge). The particular blade shape for an intended application should be chosen to focus electrical energy to produce the highest temperature over the smallest volume of tissue while minimizing power consumption, within specified manufacturing cost and complexity constraints (e.g., specified manufacturing procedure for the blade may include stamping, die cutting, and/or grinding). For each implementation, a combination of manufacturing cost, power consumption during use, and instrument functionality considerations will typically determine the particular blade size and shape.

In preferred embodiments, the inventive monopolar instrument has a blade surface made of hard, smooth, electrically conductive material having low chemical reactivity. Preferably, the material can withstand the high localized temperatures of electric discharge between the blade surface and patient tissue, so that (when the blade surface material is coated on an underlying substrate) the material does not readily burn off, melt off, or

scrape off the substrate during use. In some preferred embodiments, the inventive blade is made of (or coated with) any of the electrically conducting ceramics or cermets disclosed in pending U.S. Patent Application 08/661,980, filed June 12, 1996. Examples of such ceramics and cermets are electrically conducting Titanium Nitride, Silicon Nitride, Zirconium Oxide, or Zirconium Nitride ceramics, and electrically conducting diamond-like material. In other preferred embodiments, the inventive blade is composed of electrically conducting silicon carbide ceramic or cermet, or has a coating of electrically conducting silicon carbide ceramic or cermet over an electrically conducting substrate. In some preferred embodiments, the electrically conducting coating is deposited as a layer (whose thickness depends on the material, application and manufacturing method) on an electrically conducting substrate. The substrate can be metal (such as stainless steel, titanium, tantalum, or tungsten) or other refractory, electrically conducting material.

In embodiments in which the inventive instrument blade has a thin coating (e.g., a few microns thick) coating over a substrate, the substrate preferably has a smooth, polished surface to avoid undesirable eschar adhesion, which may otherwise occur in at least some applications. The effect of polishing the substrate to a smooth, fine surface is to minimize surface area and therefore eschar adhesion.

Another aspect of the invention is a blade (of any of the described types) alone, for use as part of a complete electrosurgical instrument.

Brief Description of the Drawings

Figure 1 is a schematic diagram of a monopolar electrosurgical instrument (which can embody the invention of the present application), and a patient on which electrosurgery is to be performed.

Figure 2 is a schematic diagram of a bipolar electrosurgical instrument, and a patient on which electrosurgery is to be performed.

Figure 3 is a perspective view of a monopolar electrosurgical instrument including a blade (a Bovie blade) according to one embodiment of the present invention.

Figure 4 is a top view of a portion of the blade of Figure 3.

Figure 5 is a side view of a portion the blade of Figure 3.

Figure 6 is a cross-sectional view of a portion of the blade of Figure 3, taken along line 6-6 of Figure 4.

Figure 7 is a perspective view of a blade of a monopolar electrosurgical instrument (a Bovie blade) having an electrically conductive ceramic or cermet coating on a core, according to another embodiment of the invention.

Figure 8 is a cross-sectional view of the blade of Figure 7, taken respectively along line 8-8 of Figure 7.

Figure 9 is a cross-sectional view of an electrosurgical blade according to a third embodiment of the invention.

Figure 10 is a cross-sectional view of an electrosurgical blade according to a fourth embodiment of the invention.

Figure 11 is a cross-sectional view of an electrosurgical blade according to a sixth embodiment of the invention.

5 Figure 12 is a cross-sectional view of an electrosurgical blade according to a seventh embodiment of the invention.

10 Figure 13 is a cross-sectional view of an electrosurgical blade (having intersecting radiused surfaces) according to an eighth embodiment of the invention.

#### Detailed Description of the Preferred Embodiments

Fig. 1 is a schematic diagram of a monopolar electrosurgical instrument, comprising electrode 103, electrosurgical pencil 101 which has a switch (not shown) for controlling current flow, power supply 102, and "patient plate" electrode 104 which is affixed to the patient. Pencil 101 (sometimes referred to herein as a "connector") is electrically connected between electrode 103 and one terminal of power supply 102 (a wire extends between pencil 101 and power supply 102), and electrode 104 is connected (by a second wire) to a second terminal of power supply 102. When the switch in pencil 101 is closed, a potential difference (typically, a time varying potential difference having specified peak-to-peak amplitude and frequency) is produced between electrodes 103 and 104. This potential difference causes electric current (typically having amplitude which varies sinusoidally at radio frequency) to flow from electrode 103, through patient 105, to patient plate electrode 104. The surface area of electrode 103 through which current flows (the "active electrode surface" of electrode 103) is small relative to the area of patient plate electrode 104

and therefore an intense local current density is generated in the patient at the location of electrode 103. This results in cutting or cauterization of the tissue in immediate proximity to electrode 103.

5        If electrode 103 is a blade that is shaped in accordance with the present invention and/or composed of material in accordance with the present invention, the monopolar instrument of Fig. 1 embodies the invention.

10        Fig. 2 is a schematic diagram of a bipolar electrosurgical instrument, which comprises electrodes 107 and 108, electrosurgical switch 106 for controlling current flow, and power supply 102. Electrodes 107 and 108 are separately connected to  
15        power supply 102. When the switch 106 is closed, a potential difference (having specified peak-to-peak amplitude and frequency) is produced between electrodes 107 and 108. This potential difference causes electric current to flow between electrodes  
20        107 and 108 through a small region of patient 105's tissue. It is not contemplated that the present invention will be embodied as a bipolar instrument, such as that shown in Fig. 2.

25        Figure 3 is a perspective view of a monopolar electrosurgical instrument 1 according to one embodiment of the present invention. Fig. 4 is a top view and Fig. 5 is a side view of distal portion 50 of blade 2 of Fig. 3. Figure 6 is a cross-sectional view of distal portion 50 of blade 2, taken along  
30        line 6-6 of Fig. 4. Electrosurgical instrument 1 has a proximal end 70 (sometimes referred to herein as "connector 70") for attachment to another connector (typically a pencil through which current can flow, such as pencil 101 of Fig. 1), and a distal end 10.  
35        Item 60 (which is typically present) is a plastic

sleeve insulator. In preferred embodiments, connector 70 and blade 2 are made from a single piece of electrically conducting material. In other embodiments the connector 70 and blade 20 are two  
5 different pieces of electrically conducting material joined in some manner at the midsection of instrument 1 and covered by insulator 60. During use, the connector 70 would be connected to pencil 101.

Blade 2 has two main surfaces 8 in addition to  
10 the two cutting surfaces 11, as best shown in the cross-sectional view of Figure 6. The edges of blade 2 are beveled in the sense that it has four angled planar surfaces 9 (in addition to surfaces 8 and 11), with one planar surface 9 between each main surface 8  
15 and each cutting surface 11 adjacent to such main surface. Each of cutting surfaces 11 has a relatively small width "t," is made of electrically conductive material, and functions efficiently as a working edge (i.e., a cutting edge or cauterizing  
20 edge). The width ("t") may be constant, or may vary slightly from cross-section to cross-section, i.e., with position along longitudinal axis L within section 50 as shown in Fig. 3.

The inventors have found that the cutting  
25 efficiency of blade 2 is dramatically increased by forming the blade so that its cross-section (in planes perpendicular to axis L) satisfies at least one, and preferably both, of the following criteria:

the angle ( $\theta$  in figure 5) between each cutting  
30 surface 11 and each surface 9 (i.e., between the plane of each surface 11 and the plane of each surface 9) is at least 50 degrees; and

the ratio of cutting surface width "t" (shown in Fig. 6) to blade thickness "2a" (also shown in Fig.

6) is less than  $1/3$  (in other words, " $t/2a$ " is less than  $1/3$ ).

Each cutting surface 11 is oriented parallel to planar surface A (perpendicular to the plane of Fig. 6) which is normal to the planar surfaces 8 (as shown in Fig. 6), and each surface 9 is oriented at an angle at least 50 degrees with respect to the planar surface A. For example, the upper left surface 9 of Fig. 6 is oriented along plane B, and the angle ( $\theta$ ) between planar surface A and planar surface B is at least 50 degrees.

In contrast, conventional monopolar electrosurgical blades are rectangular in cross-section (or approximately rectangular, with rounded rather than sharp corners). Such a rectangular (or approximately rectangular) cross-section is equivalent to a modification of the inventive cross-section of Fig. 6, in which surfaces 9 have been rotated to be coplanar with surfaces 11 so that angle  $\theta$  is decreased to 0 degrees. The inventors have recognized that the conventional cross-sectional blade shapes are inefficient for monopolar cutting.

The inventors' carefully controlled experiments have shown that by properly shaping a monopolar instrument's electrode cross-section to produce very high temperatures in small volumes of tissue, more efficient cutting or cauterization can be achieved. The expression "more efficient" with reference to cutting or cauterization herein denotes more rapid movement of the blade through patient tissue (i.e., more rapid than can be achieved by conventional blades using the same cutting force). Rapid movement through tissue is desirable for several reasons. As the blade moves more rapidly through tissue, the arc does not have as long a dwell time at a given

location, and eschar is not created as readily as in the case of slower motion. Thus, less tissue "browning" occurs, and less smoke is generated as a result of less browning. Eschar creation is also reduced.

The invention is based on the inventors' recognition that since RF power (as used in electrosurgery) tends to flow across interfaces with differing impedances (such as blade-tissue interfaces) in such a way as to focus the current flow at sharp corners or points, the cutting efficiency of monopolar instruments can be improved by appropriately shaping the electrode cross-section. With this in mind, the inventors determined that specific cross-sectional shapes result in dramatically improved cutting efficiency, namely the shape described with reference to Figs. 3-6, and the shapes to be described with reference to Figs. 9-13. Each of the inventive cross-sectional shapes focuses RF energy at a working edge (i.e., a cutting edge or cauterizing edge) or a small number of working edges of the instrument blade, causing a high current density at each working edge. For convenience, the "working" edges of the various embodiments described herein are sometime referred to as "cutting" edges (although they are useful for performing efficient cauterizing as well as efficient cutting). For example, in the embodiment of Figs. 3-6, the shape of blade 2 focuses RF energy at cutting surfaces 11 (each cutting surface 11 is referred to as a cutting edge). Thus, the shape of blade 2 results in high current density at each cutting edge 11.

The inventive monopolar electrode blade can alternatively be implemented to have other cross-sectional shapes (shapes other than those shown in

Figs. 6 and 9-13) which focus RF energy at a cutting edge (or a small number of cutting edges), causing a high current density at each cutting edge. The particular blade shape for an intended application should be chosen to focus electrical energy to produce the highest temperature over the smallest volume of tissue while minimizing power consumption, within specified manufacturing cost and complexity constraints (e.g., specified manufacturing procedure for the blade may include stamping, die cutting, and/or grinding). A combination of manufacturing cost, power consumption during use, and instrument functionality will typically determine the particular blade size and shape.

With reference again to Figs. 3-6, blade 2 would typically be implemented to have cross-sectional width "2b" on the order of 0.1 inches, and cross-section thickness "2a" on the order of 0.02 inches, as would conventional electrosurgical blades. In some embodiments of the inventive electrosurgical blades, the dimensions "2a" and "2b" of position 50 may vary with position along the longitudinal axis L.

In preferred implementations, blade 2 is made of a substrate material such as stainless steel, titanium, tungsten, tantalum or another metal and a coating on the substrate of any of the electrically conductive ceramics or cermets described in pending U.S. Patent Application 08/661,980, filed June 12, 1996. Examples of such ceramics and cermets are electrically conducting Titanium Nitride, Silicon Nitride, Silicon Carbide, Zirconium Oxide, or Zirconium Nitride ceramics, Boron Carbide-Aluminum ( $B_4C-Al$ ) cermets, Silicon Carbide cermets, and electrically conducting diamond-like carbon material. In other preferred implementations, blade 2 is

composed entirely of electrically conducting ceramic or electrically conducting cermet materials.

5 In another such preferred implementation, blade 2 comprises electrically conductive, diamond-like material. The expression "diamond-like material" is used herein to denote materials having a crystal structure like that of a diamond (comprising carbon in a predominate  $sp^3$  bonding configuration) and consisting predominantly of carbon atoms, but which  
10 includes any of a wide variety of other atoms (and/or other networks of atoms) that cause the material to be electrically conductive. In contrast, pure diamond material is electrically insulating.

15 Preferably, the electrically conductive ceramic or cermet forming blade 2 is chemically passive. The electrically conductive ceramics and cermets described in pending U.S. Patent Application 08/661,980 satisfy this criterion. It is important to note that only the active electrode surface of  
20 blade is in contact with a carburizing environment, and thus in alternative embodiments, only the active electrode surface of the blade is made of chemically passive, electrically conductive material. For example, in preferred implementations of the Fig. 7 embodiment (to be described below), so long as each  
25 active electrode surface is made of chemically passive, electrically conductive ceramic or cermet material, the remainder of the blade may be made of any suitable material or materials. For instance, to  
30 improve the mechanical properties of the instrument, a chemically passive, electrically conductive material can be coated onto a metal core (or other supporting substrate).

35 Another preferred embodiment of the invention will be described with reference to Figs. 7 and 8.

In this embodiment, the blade of the inventive instrument (blade 100) comprises an electrically conductive substrate (core 140) made of metal (e.g., stainless steel, titanium, tantalum, tungsten) or refractory, electrically conducting material, and an electrically conductive ceramic or cermet coating (coating 150) on the substrate. In alternative implementations, core 140 is made of electrically insulating material (but the subsequent description of Figs. 7 and 8 will assume that core 140 is electrically conducting).

In preferred implementations, coating 150 of blade 100 of Fig. 7 (and Fig. 8) is made of any of the electrically conductive ceramics or cermets described in pending U.S. Patent Application 08/661,980. In other preferred implementations, coating 150 of blade 100 is electrically conducting silicon carbide material. In some preferred embodiments, electrically conducting coating 150 is deposited as a thin layer (e.g., having thickness of only a few microns) on electrically conducting substrate 100.

In the Fig. 7 embodiment, as in all embodiments in which the inventive instrument blade has a thin coating over a substrate (e.g., a coating of thickness a few microns, which is typically preferable from a manufacturing cost point of view, although it should be recognized that no actual limit exists on the coating thickness because the material is electrically conducting), the substrate preferably has a smooth, polished surface (at the interface with the coating, e.g. at interface 170 between coating 150 and substrate 140 of Fig. 7). The smooth, polished surface is polished to reduce surface roughness and avoid undesirable eschar adhesion,

which may otherwise occur in at least some applications. In some embodiments, the substrate is should be polished to have a surface roughness of no more than 10 microns RMS.

5           Figure 7 is a perspective view of blade 100 (a Bovie blade) of a monopolar electrosurgical instrument that embodies the invention. Figure 8 is a cross-sectional view of blade 100, taken along line 8-8 of Fig. 7. Blade 100 has a distal cutting tip 110, two side cutting surfaces 120 (also referred to as cutting "edges"), and a proximal end 130. Proximal end 130 is to be attached to a connector (when the entire instrument is made from two pieces, as are some embodiments of the instrument described earlier with reference to Fig. 3).

10           Blade 100 has two main surfaces 165 in addition to the two side cutting surfaces 120, as best shown in the cross-sectional view of Figure 8. The edges of blade 100 are beveled in the sense that the blade has four angled planar surfaces 160 (in addition to surfaces 165 and 120), with one surface 165 between each main surface 165 and each cutting surface 120 adjacent to such main surface. Each of cutting surfaces 120 has relatively small width "t," is made of electrically conductive material, and functions efficiently as a cutting edge. The width "t" may vary slightly from cross-section to cross-section, i.e., with position along the longitudinal axis of blade 100 (from proximal end 130 to tip 110). In preferred implementations, core 140 is made entirely of electrically conductive material so that current can flow from the power supply, through each of side cutting surfaces 120 and tip 110, to the patient tissue.

The inventors have found that the cutting efficiency of blade 100 (like that of blade 2 of Fig. 3) is dramatically increased by forming the blade so that its cross-section (in planes perpendicular to the longitudinal axis, such as the plane of Fig. 8) satisfies at least one, and preferably both, of the following criteria:

the angle ( $\theta$ ) between each cutting surface 120 and each surface 160 (i.e., between the plane of each surface 120 and the plane of each surface 160) is at least 50 degrees; and

the ratio of cutting surface width "t" (shown in Fig. 8) to blade thickness "2a" (also shown in Fig. 8) is less than  $1/3$  (in other words, " $t/2a$ " is less than  $1/3$ ).

With reference to Fig. 7, there is an interface reaction zone 170 between core 140 and conductive coating 150. Cutting tip 110 and edges 120 of blade 100 are made of a cermet or ceramic having good electrical conductivity. In variations on the embodiment of Figs. 7 and 8, Bovie blades similar to the one shown in Figs. 7 and 8 are made using one of several combinations of a metal core and a conducting ceramic coating (including carbide and/or boride coatings WC, MoC, TiC,  $TiB_2$ , TiNC, and NbC) on the surface of a metal (W, Mo, Ti, and Nb) core.

In one preferred implementation, blade 100 comprises a core 140 made of metal, and electrically conductive, diamond-like carbon material deposited thereon by ion beam deposition or plating (IBD) to form coating 150. The deposition process forms carbon ions or other ions with an electrical discharge and accelerates these ions in a potential gradient to impinge the ions onto the substrate, thereby precipitating a diamond-like, electrically

conductive structure on the substrate. The IBD process allows a high degree of control so that other conducting ions and network structures can be introduced to form electrically conductive coatings. The accelerated ions are also driven into the surface of the substrate for better bonding at lower temperatures.

Figure 9 is a cross-sectional view of electrosurgical blade 200 according to a third embodiment of the invention. Blade 200 is a variation on blade 2 (described with reference to Figs. 3-6), in which the side cutting edges are sharp (rather than truncated, as are cutting edges 11 of blade 2). Blade 200 has two parallel main surfaces 204, and four side cutting surfaces 202 between main surfaces 204. Two surfaces 202 meet at first sharp cutting edge 206, and the other two surfaces 202 meet at second sharp cutting edge 207.

The inventors have found that the cutting efficiency of blade 200 is dramatically increased by forming the blade so that its cross-section (in planes perpendicular to its longitudinal axis, e.g., the plane of Fig. 9) satisfies the criterion that the angle ( $\theta$ ) between a plane normal to each of surfaces 204, and the plane of each surface 202 is at least 50 degrees.

In preferred implementations, blade 200 is made of any of the electrically conductive ceramics or cermets used in preferred implementations of above-described blade 2. Alternatively, blade 200 has a metal core, and the core is coated with any of such electrically conductive ceramics or cermets, so that each of surfaces 202 and edges 206 and 207 consists of conductive ceramic or cermet material.

Figure 10 is a cross-sectional view of electrosurgical blade 300 according to a fourth embodiment of the invention. Blade 300 is a variation on blade 2 (described with reference to Figs. 3-6), with an elliptical cross-section (rather than a rectangular cross-section with beveled surfaces as blade 2 has). The cutting surfaces of blade 300 are the portions of the blade having greatest curvature (i.e., the upper and lower portions 306 and 307 respectively in Fig. 10). Such portions of greatest curvature are referred to herein as the "working" edges of blade 300.

The inventors have found that the cutting efficiency of blade 300 is dramatically increased by forming the blade so that the aspect ratio (the ratio of major axis to minor axis) of its cross-section (in planes perpendicular to its longitudinal axis, e.g., the plane of Fig. 10) is greater than four. In other words, the aspect ratio should satisfy  $2b/2a > 4$ , where "2b" is the major axis and "2a" is the minor axis of the cross-section (as shown in Fig. 10).

Other preferred implementations of the invention have an approximately elliptical blade cross-section, e.g., the cross-section shown in Fig. 13 (which closely approximates the cross-sectional shape of the Fig. 10 embodiment utilizing a series of intersecting radiused surfaces). Blade 600 of Fig. 13 is a variation on blade 300 (described with reference to Fig. 10) which has an approximately elliptical cross-section comprising two "side" portions 604 (each having a relatively large radius of curvature  $R_2$ ) and two end portions (606 and 607), each having a relatively small radius of curvature  $R_1$ . The cross-section of blade 60 has four points of intersection (labeled as points "A" in Fig. 13), each point A

located between one of surfaces 604 and either surface 606 or 607 (as shown in Fig. 13). The cutting surfaces of blade 600 are portions 606 and 607, which have the greatest curvature. Such portions of greatest curvature are referred to herein as the "working" edges of blade 600. The inventors have found that the cutting efficiency of blade 600 is dramatically increased by forming the blade so that the aspect ratio (the ratio of major axis to minor axis) of its cross-section (in planes perpendicular to its longitudinal axis, e.g., the plane of Fig. 13) is greater than four. In other words, the aspect ratio should satisfy  $2b/2a > 4$ , where "2b" is the major axis and "2a" is the minor axis of the cross-section (as shown in Fig. 13). Also, twice the radius of curvature,  $R_1$ , of edges 606 and 607 (in the Fig. 13 embodiment) is preferably less than one third of the blade thickness, 2a (i.e.,  $2R_1/2a < 1/3$ ) in order for the blade to have the desired energy focusing properties.

In preferred implementations, blade 300 of Fig. 10 (or blade 600 of Fig. 13) is made of any of the electrically conductive ceramics or cermets used in preferred implementations of above-described blade 2. Alternatively, blade 300 (or 600) has a metal core, and the core is coated with any of such electrically conductive ceramics or cermets.

Figure 11 is a cross-sectional view of electrosurgical blade 400 according to a sixth embodiment of the invention. Blade 400 is a variation on blade 200 (described with reference to Fig. 9), in which the cutting surfaces are concave (rather than planar, as are cutting surfaces 202 of blade 200). Blade 400 has two parallel main surfaces 404, and four curved (concave) side cutting surfaces

402 between main surfaces 404. Two surfaces 402 meet at first sharp cutting edge 406, and the other two surfaces 402 meet at second sharp cutting edge 407. There is an edge 408 between each surface 402 and the main surface 404 adjacent to such surface 402.

The inventors have found that the cutting efficiency of blade 400 is dramatically increased by forming the blade so that its cross-section (in planes perpendicular to its longitudinal axis, e.g., the plane of Fig. 11) satisfies the criterion that the angle ( $\theta$ ) between a plane normal to the intersection of each of surfaces 404 with the plane of Fig. 10, and each axis (in the plane of Fig. 11) containing edge 406 and each of the edges 408 nearest thereto (or edge 407 and each of the edges 408 nearest thereto) is at least 50 degrees. Thus, the angle ( $\theta$ ) between normal axis A (normal to the intersections of surfaces 404 with the plane of Fig. 11) and axis B (containing edge 406 and the left edge 408 nearest to edge 406) is at least 50 degrees.

In preferred implementations, blade 400 is made of any of the electrically conductive ceramics or cermets used in preferred implementations of above-described blade 2. Alternatively, blade 400 has a metal core, and the core is coated with any of such electrically conductive ceramics or cermets, so that each of surfaces 402 and edges 406 and 407 consists of conductive ceramic or cermet material.

Figure 12 is a cross-sectional view of electrosurgical blade 500 according to a seventh embodiment of the invention. Blade 500 is a variation on blade 400 (described with reference to Fig. 11), with convex cutting 502 surfaces (rather than concave cutting surfaces 402 as has blade 400). Blade 500 has two parallel main surfaces 504, and

four curved (convex) side cutting surfaces 502 between main surfaces 504. Two surfaces 502 meet at first sharp cutting edge 506, and the other two surfaces 502 meet at second sharp cutting edge 507. There is an edge 508 between each surface 502 and the main surface 504 adjacent to such surface 502.

The inventors have found that the cutting efficiency of blade 500 is dramatically increased by forming the blade so that its cross-section (in planes perpendicular to its longitudinal axis, e.g., the plane of Fig. 12) satisfies the criterion that the angle ( $\theta$ ) between a plane normal to each of surfaces 504, and each plane containing edge 506 and tangent to surface 502 at edge 506 (or edge 507) is at least 50 degrees. In preferred implementations, blade 500 is made of any of the electrically conductive ceramics or cermets used in preferred implementations of above-described blade 2. Alternatively, blade 500 has a metal core, and the core is coated with any of such electrically conductive ceramics or cermets, so that each of surfaces 502 and edges 506 and 507 consists of conductive ceramic or cermet material.

It should be appreciated that the following definitions apply throughout this disclosure:

**Electrosurgical instrument** - any surgical instrument that is used for supplying electrical current to a patient or other subject. The subject may be either animal or human. Examples of electrosurgical instruments include, but are not limited to, Bovie Blades, bipolar forceps, cauterizing end effectors (for endoscopic surgery), bipolar biopsy devices, spatula blades, ball electrodes, arthroscopic hook electrodes, L and J hook electrodes (for laparoscopic surgery), extended

blade electrodes, needle electrodes, extended needle electrodes, curved electrode, angled blade electrode, and loop electrodes (for histological examinations and gynecologic tissue extractions).

5       **Active Electrode Surface** - that area of the surface of an electrosurgical instrument through which electric current is supplied to the subject.

10       **Ceramic** - A material useful for making solid articles which has as its essential component, and is composed in large part of, one or more inorganic, nonmetallic materials. Examples of such materials include refractory, covalent and most ionic bonded materials.

15       **Conducting ceramic** - a ceramic that is an electrical conductor. Specifically, a ceramic that has a large enough electrical conductivity that it may be used as an active electrode surface in an electrosurgical instrument.

20       **Cermet** - a material consisting of a mixture of ceramic and metallic components that has a large enough electrical conductivity that it may be used as an active electrode surface in an electrosurgical instrument.

25       **Carbide, Boride, Nitride, Oxide and mixed Ceramics** - ceramics that include carbon, boron, nitrogen, oxygen, or mixtures thereof, respectively. Specific ceramics are denoted by either their name or chemical formula. For example, Tungsten Carbide or WC. The chemical formula does not denote the stoichiometry of the material but merely the  
30       elemental composition.

**Conducting composite ceramic** - a mixture of two or more ceramic materials in which one or more of the ceramics has a large enough electrical conductivity

that the composite ceramic may be used as an active electrode surface in an electrosurgical instrument.

One class of electrically conductive materials that can be used to form the active electrode surface

5 of the inventive instrument blade are carbide ceramics, boride ceramics, nitride ceramics, and mixtures of these ceramics. Suitable ceramics in this class include (but are not limited to) the systems of Boron Carbide ( $B_4C$ ), Tungsten Carbide ( $WC$ ),  
10 Titanium Carbide ( $TiC$ ), Molybdenum Carbide ( $MoC$ ), Niobium Carbide ( $NbC$ ), Zirconium Carbide ( $ZrC$ ), Titanium Boride ( $TiB_2$ ), Titanium Nitride ( $TiN$ ), Aluminum Nitride ( $AlN$ ), Zirconium Nitride ( $ZrN$ ), Zirconium Boride ( $ZrB_2$ ), Vanadium Carbide ( $VC$ ),  
15 Hafnium Carbide ( $HfC$ ), and Tantalum Carbide ( $TaC$ ).

The most common stoichiometries for these ceramics are shown in parentheses. These materials possess many properties useful in the present invention including good electrical conductivity, good thermal  
20 conductivity, and excellent hardness properties. In fact, these ceramics are some of the hardest materials known and are resistant to scratching and pitting. Since tissue build up and adhesion is increased by rough surfaces, the hardness property  
25 helps further reduce tissue adhesion. Furthermore, these materials do not substantially react in the carburizing environment present in the electrosurgical procedure and therefore do not suffer from significant eschar adhesion.

30 As is well known in the art, altering the carbon, nitrogen, and boron content in these systems effects their electrical and thermal properties, and each system can be adjusted to get an optimum stoichiometry and/or phase for a specific  
35 electrosurgery application.

The carbide ceramics, boride ceramics, nitride ceramics, and mixtures thereof can be prepared by conventional methods including direct union of the elements at high temperatures (1600°C and above for the carbides), and heating a compound of the metal, particularly the oxide, with carbon, boron or mixtures thereof. The carbides may also be prepared by heating the metal in the vapor of a suitable hydrocarbon. The borides may also be prepared by reacting the metals or their oxides with  $B_2O_3$  and C, or with  $B_4C$ . This reaction results in the evolution of CO and the formation of the metal boride ceramic. Boron carbide ( $B_4C$ ) may be prepared by the reduction of  $B_2O_3$  with carbon in an electric furnace. These preparation methods are well known in the art. The conducting ceramics may be formed into the required shapes for the electrosurgical instruments using convention ceramic processing techniques including injection molding, slip casting, cold pressing, hot pressing, and isostatic hot pressing (HIP).

In other embodiments of the invention, each active electrode surface consists of a conducting ceramic formed by finely dispersing a carbide ceramic, boride ceramic, or nitride ceramic, or mixture thereof in a non-electrically conducting ceramic matrix. As an example, TiC particles (>25 weight %) may be uniformly dispersed in an  $Al_2O_3$  matrix to yield a conducting ceramic. The proportion of the conducting ceramic and the uniformity of its dispersion in the non-conducting matrix must be controlled to ensure that the resulting material is a conducting ceramic. Examples of suitable non-conducting ceramics include  $Al_2O_3$ , MgO,  $SiO_2$ , silicates,  $HfO_2$ , BeO, and  $TiO_2$ . These ceramic composites may be prepared using standard techniques

including slip casting, and hot pressing. The ceramic composites may be shaped into electrosurgical instruments using standard processing techniques including injection molding, slip casting, cold press and sinter, hot pressing, and isostatic hot pressing (HIP).

In embodiments in which the conducting ceramic active electrode surface is supported on a substrate, the conducting ceramic may be formed on the substrate using standard processing techniques including physical vapor deposition, chemical vapor deposition, sputter coating, laser deposition, flame spray, and plasma jet spray coating. If the substrate is a metal core, the conductive ceramic active electrode surface may be formed as a coating on the surface of the substrate by reacting the metal core with suitable carbon, boron, or nitrogen containing compounds.

Other electrically conductive materials that can be used to form the active electrode surface of the inventive instrument blade are electrically conductive cermets. These materials possess the same useful properties as the ceramics described above (good electrical and thermal conductivity and hardness) together with the additional advantage that they are less brittle than the pure ceramic. For this reason, in applications in which the electrosurgical instrument may have to operate under tensile loads, it will typically be desirable to fabricate the blade out of cermet materials rather than ceramics. Generally, any cermet that is substantially unreactive in the carburizing atmosphere of the electrosurgical procedure and that is capable of carrying sufficient current to perform electrosurgery may be used in the present invention.

More particularly, cermets that may be used in the present invention include materials composed of one or more metals together with a carbide, boride, or nitride ceramic (or mixture thereof). Examples of  
5 suitable metals include Ag, Cu, Pt, Ta, V, Co, Ni, Fe, Mo, Ti, Hf, Zr, Nb, W and Al and examples of suitable ceramics include WC, TiC, TiB<sub>2</sub>, TiN and B<sub>4</sub>C. The cermets may be prepared using conventional methods including cold press and sintering, hot  
10 pressing, isostatic hot pressing, and molten metal infiltrating.

As in the case of the ceramics described above, a cermet material may be formed into electrosurgical instruments using conventional techniques including  
15 injection molding, slip casting, cold press and sinter, hot pressing, isostatic hot pressing, and molten metal infiltration.

An electrically conducting cermet active electrode surface can be supported on a substrate.  
20 In this case, the conducting cermet can be formed on the substrate using standard processing techniques including physical vapor deposition, chemical vapor deposition, sputter coating, laser deposition, molten metal infiltration and plasma jet spray coating. If  
25 the substrate is a metal core, the conductive cermet active electrode surface may be formed as a coating on the surface of the support means by reacting the metal core with suitable carbon, boron, or nitrogen containing compounds.

30 B<sub>4</sub>C-Al cermet (as well as WC-Co, WC-Ni-Fe, and TiC-Mo-Ni cermets) is especially well suited for use in electrosurgical instruments due to its high hardness, reaction resistance, and non-toxic components (B, C and Al). The by-products (B<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub>  
35 and CO<sub>2</sub>) from reaction of the B<sub>4</sub>C-Al cermet electrodes

are more compatible with the human body than most other cermet and metal systems including the stainless steel and Teflon coated electrodes described above. B<sub>4</sub>C-Al cermets have been

5 demonstrated to work as effective electrosurgical instruments including Bovie blades, and bipolar forceps tips. Depending on the specific application, the composition of the B<sub>4</sub>C-Al cermet is altered slightly, however, most compositions are within a

10 range of 25 to 80 weight percent B<sub>4</sub>C and the remaining balance Al or an Al alloy. The composition and fabrication of B<sub>4</sub>C-Al cermet systems are described in US Patents No. 4,605,440 and No. 4,718,941, the disclosures of which are incorporated herein by

15 reference.

Many cermets are useful in magnetic resonance imaging (MRI) applications where most metal tools (stainless steel, steel, nickel, etc.) cannot be used without distorting the image or causing safety

20 hazards in the MRI environment. In preferred embodiments of the invention, the ceramic or cermet material forming the active electrode surface of the inventive blade is of a type suitable for use in MRI applications (e.g., those in which the electrode is

25 to be imaged by MRI).

In alternative embodiments, the inventive electrosurgical instrument blade comprises an electrically insulating substrate, and at least one electrically conducting active electrode surface

30 coated (or otherwise supported) on the insulating substrate.

Preferably, when the inventive electrosurgical instrument blade comprises at least one electrically conducting ceramic or cermet active electrode surface

35 coated (or otherwise supported) on a substrate, the

substrate is electrically conducting. For example, a metal core may be coated with an electrically conducting ceramic or cermet. Many of the metals (W, Mo, Ti, Nb, Ta, Zr, Ni, Hf, Al, and V) and their alloys used to make the ceramics described above have relatively good tensile strengths. Therefore, by first forming a metal core and subsequently forming a carbide, boride, or nitride ceramic or mixture of these ceramics on the surface of the metal it is possible to prepare an electrosurgical instrument that retains the tensile strength of the metal core while improving the hardness and reaction resistance of the active electrode surface. The ceramic layer may be formed using conventional preparation techniques including heating the metal core in a carbon, boron, or nitrogen atmosphere or mixture of these atmospheres. For carbide ceramic or cermet coatings, the coating may also be formed by heating the metal core in a hydrocarbon atmosphere or carbon powder, and for boride ceramic or cermet coatings the coating may be formed by heating the metal core in boron powder (or a boron halide and hydrogen atmosphere). For nitride ceramic or cermet coatings the coating may be formed by heating the metal core in an ammonium or nitrogen atmosphere.

Using these preparation methods it is relatively easy to control the thickness of the ceramic layer deposited on the metal core. The ceramic layer must be thick enough that no metal is exposed during use of the instrument in electrosurgical procedures, but it should not be so thick as to lose the tensile strength advantages due to the metal core. Suitable ceramic layer thickness depends on the size and configuration of the instrument.

Carbide, boride, or nitride ceramic coatings, or mixtures of these ceramic coatings may also be applied by conventional coating techniques including physical vapor deposition, chemical vapor deposition, sputter coating, laser deposition, flame spray, and plasma jet spray coating. Such techniques increase the options available since the ceramic coating is not limited to include the same metal as the core. For example, a Titanium Nitride or Tungsten Carbide coating may be applied to a Ti metal core to form an electro-surgical instrument, a Tungsten metal core may be plasma coated with Titanium Carbide, and diamond-like coatings may be deposited to a Titanium metal core.

Another advantage of metal-cored embodiments of the invention is due to the high thermal conductivity of the metal core. This results in the heating of the electrode surface being efficiently dissipated and this acts to further reduce the tissue build up during the electro-surgery.

Various modifications and variations of the described embodiments of the invention will be apparent to those skilled in the art without departing from the scope and spirit of the invention. Although the invention has been described in connection with specific preferred embodiments, it should be understood that the invention as claimed should not be unduly limited to such specific embodiments.

## WHAT IS CLAIMED IS:

1. A monopolar electrosurgical instrument configured to be powered by a current source, the instrument comprising:

5       a blade having an electrically conductive active electrode surface, a tip, and a proximal end separated along a longitudinal axis from the tip, wherein the active electrode surface has at least one electrically conductive working edge shaped to focus  
10       electrical energy from the current source so that the energy causes efficient cutting or cauterization of tissue when each said working edge is positioned adjacent to the tissue.

2. The instrument of claim 1, also including:

15       a connector to which the proximal end of the blade is mounted, wherein the connector is configured to pass electrical current from the current source to the blade, and wherein the blade has two main surfaces, each said working edge is distinct from the  
20       main surfaces, the blade has a cross-section in a plane perpendicular to the longitudinal axis, the cross-section determines a planar surface that is normal to the main surfaces and to the plane, and each said working edge is oriented at an edge angle  
25       of at least 50 degrees with respect to the planar surface.

3. The instrument of claim 2, wherein the active electrode surface is made of hard, smooth, electrically conductive material having low chemical  
30       reactivity.

4. The instrument of claim 3, wherein the active electrode surface is made of electrically conducting diamond-like material.

5 5. The instrument of claim 1, wherein each said working edge is a sharp working edge.

6. The instrument of claim 1, wherein each said working edge is shaped to focus the electrical energy to maximize temperature over a minimum volume of the tissue while minimizing power consumption, within  
10 specified manufacturing cost and complexity constraints.

7. The instrument of claim 1, wherein the blade has a cross-section in a plane perpendicular to the longitudinal axis, and the cross-section is an  
15 elliptical cross-section having an aspect ratio greater than four.

8. The instrument of claim 7, wherein the active electrode surface is made of hard, smooth, electrically conductive material having low chemical  
20 reactivity.

9. The instrument of claim 8, wherein the active electrode surface is made of electrically conducting diamond-like material.

10. The instrument of claim 1, wherein the blade  
25 has a cross-section in a plane perpendicular to the longitudinal axis, the cross-section is an approximately elliptical cross-section determined by intersecting radiused surfaces, and the cross-section has an aspect ratio greater than four.

11. The instrument of claim 10, wherein the cross-section has a minor axis, two of the radiused surfaces are cutting surfaces, another two of the radiused surfaces are side surfaces, each of the side surfaces has a first radius of curvature, each of the cutting surfaces has a second radius of curvature smaller than the first radius of curvature, and twice the second radius of curvature is less than one third as long as the minor axis.

12. The instrument of claim 10, wherein the active electrode surface is made of hard, smooth, electrically conductive material having low chemical reactivity.

13. The instrument of claim 1, wherein the blade has two main surfaces, each said working edge is a truncated, beveled working edge distinct from the main surfaces, the blade has a cross-section in a plane perpendicular to the longitudinal axis, the cross-section has a maximum width in a direction normal to the intersection of the main surfaces and the plane, and each said working edge has a minimum width in the direction normal to the intersection of the main surfaces and the plane, and the ratio of the minimum width to the maximum width is less than  $1/3$ .

14. The instrument of claim 13, wherein the active electrode surface is made of hard, smooth, electrically conductive material having low chemical reactivity.

15. The instrument of claim 14, wherein the active electrode surface is made of electrically conducting diamond-like material.

16. The instrument of claim 1, wherein the active electrode surface is made of hard, smooth, electrically conductive material having low chemical reactivity.

5           17. The instrument of claim 16, wherein the active electrode surface is made of electrically conducting diamond-like material.

10           18. The instrument of claim 1, wherein the active electrode surface is made of an electrically conducting ceramic or cermet.

19. The instrument of claim 18, wherein the active electrode surface is made of an electrically conducting silicon carbide ceramic or cermet.

15           20. The instrument of claim 18, wherein the active electrode surface is made of electrically conducting diamond-like material.

21. The instrument of claim 18, wherein the entire blade is made of said electrically conducting ceramic or cermet.

20           22. The instrument of claim 18, wherein the blade includes:

a substrate, and the active electrode surface is a coating of said electrically conducting ceramic or cermet on the substrate.

25           23. The instrument of claim 22, wherein the active electrode surface is made of an electrically conducting silicon carbide ceramic or cermet.

24. The instrument of claim 22, wherein the active electrode surface is made of electrically conducting diamond-like material.

5 25. The instrument of claim 22, wherein the substrate is an electrically conducting substrate.

26. The instrument of claim 25, wherein the substrate has an electrically conducting ceramic or cermet coating.

10 27. The instrument of claim 26, wherein the substrate has a smooth, polished surface, and the coating is formed on the smooth, polished surface.

15 28. The instrument of claim 1, wherein the blade has two main surfaces, two angled surfaces which intersect at the working edge, and two non-working edges, one of the non-working edges between each of the angled surfaces and one of the main surfaces, and wherein the blade has a cross-section in a plane perpendicular to the longitudinal axis, the cross-section determines a planar surface that is normal to  
20 the main surfaces and to the plane, and each plane between the working edge one of the non-working edges is oriented at an edge angle of at least 50 degrees with respect to the planar surface.

25 29. The instrument of claim 28, wherein each of the angled surfaces is flat.

30. The instrument of claim 28, wherein each of the angled surfaces is concave.

31. The instrument of claim 28, wherein each of the angled surfaces is concave.

32. A blade for use as part of a monopolar electrosurgical instrument configured to be powered  
5 by a current source, the blade comprising:

an electrically conductive active electrode surface;

a tip; and

10 a proximal end separated along a longitudinal axis from the tip, wherein the active electrode surface has at least one electrically conductive working edge shaped to focus electrical energy from the current source so that the energy causes  
15 efficient cutting or cauterization of tissue when each said working edge is positioned adjacent to the tissue.

33. The blade of claim 32, also including:

two main surfaces, wherein each said working edge is distinct from the main surfaces, and wherein  
20 the blade has a cross-section in a plane perpendicular to the longitudinal axis, the cross-section determines a planar surface normal to the main surfaces and to the plane, and each said working edge is oriented at an edge angle of at least 50  
25 degrees with respect to the planar surface.

34. The blade of claim 33, wherein the active electrode surface is made of hard, smooth, electrically conductive material having low chemical reactivity.

35. The blade of claim 33, wherein the active electrode surface is made of electrically conducting diamond-like material.

5 36. The blade of claim 32, wherein each said working edge is a sharp working edge.

37. The blade of claim 32, wherein each said working edge is shaped to focus the electrical energy to maximize temperature over a minimum volume of the tissue while minimizing power consumption, within  
10 specified manufacturing cost and complexity constraints.

38. The blade of claim 32, wherein the blade has a cross-section in a plane perpendicular to the longitudinal axis, and the cross-section is an  
15 elliptical cross-section having an aspect ratio greater than four.

39. The blade of claim 38, wherein the active electrode surface is made of hard, smooth, electrically conductive material having low chemical  
20 reactivity.

40. The blade of claim 39, wherein the active electrode surface is made of electrically conducting diamond-like material.

41. The blade of claim 32, wherein the blade has  
25 two main surfaces, each said working edge is a truncated, beveled working edge distinct from the main surfaces, the blade has a cross-section in a plane perpendicular to the longitudinal axis, the cross-section has a maximum width in a direction

normal to the intersection of the main surfaces and the plane, and each said working edge has a minimum width in the direction normal to the intersection of the main surfaces and the plane, and the ratio of the minimum width to the maximum width is less than 1/3.

42. The blade of claim 41, wherein the active electrode surface is made of hard, smooth, electrically conductive material having low chemical reactivity.

43. The blade of claim 42, wherein the active electrode surface is made of electrically conducting diamond-like material.

44. The blade of claim 32, wherein the active electrode surface is made of hard, smooth, electrically conductive material having low chemical reactivity.

45. The blade of claim 44, wherein the active electrode surface is made of electrically conducting diamond-like material.

46. The blade of claim 32, wherein the active electrode surface is made of an electrically conducting ceramic or cermet.

47. The blade of claim 46, wherein the active electrode surface is made of an electrically conducting silicon carbide ceramic or cermet.

48. The blade of claim 46, wherein the active electrode surface is made of electrically conducting diamond-like material.

49. The blade of claim 46, wherein the active electrode surface is made of an electrically conducting ceramic comprising a first ceramic selected from the group consisting of carbide  
5 ceramics, boride ceramics, nitride ceramics, and mixtures of these ceramics.

50. The blade of claim 46, wherein the active electrode surface is made of an electrically conducting ceramic comprising a first ceramic  
10 selected from the group consisting of Boron Carbide, Tungsten Carbide, Titanium Carbide, Molybdenum Carbide, Niobium Carbide, Zirconium Carbide, Titanium Boride, Zirconium Boride, Vanadium Carbide, Hafnium Carbide, Titanium Nitride, Aluminum nitride,  
15 Zirconium Nitride, Tantalum Carbide, and combinations thereof.

51. The blade of claim 46, wherein the active electrode surface is made of an electrically conducting cermet including a metal selected from the  
20 group consisting of Silver, Hafnium, Copper, Platinum, Tantalum, Vanadium, Tungsten, Titanium, Zirconium, Niobium, Cobalt, Nickel, Iron, Molybdenum, and Aluminum.

52. The blade of claim 46, wherein the entire  
25 blade is made of said electrically conducting ceramic or cermet.

53. The blade of claim 46, wherein the blade includes:  
a substrate, and the active electrode surface is  
30 a coating of said electrically conducting ceramic or cermet on the substrate.

54. The blade of claim 53, wherein the active electrode surface is made of an electrically conducting silicon carbide ceramic or cermet.

5 55. The blade of claim 53, wherein the active electrode surface is made of electrically conducting diamond-like material.

56. The blade of claim 53, wherein the substrate is an electrically conducting substrate.

10 57. The blade of claim 56, also including an electrically conducting ceramic or cermet coating on the substrate.

58. The blade of claim 57, wherein the substrate has a smooth, polished surface, and the coating is formed on the smooth, polished surface.

15 59. The blade of claim 32, wherein the blade has a cross-section in a plane perpendicular to the longitudinal axis, the cross-section is an approximately elliptical cross-section determined by intersecting radiused surfaces, and the cross-section  
20 has an aspect ratio greater than four.

60. The blade of claim 59, wherein the cross-section has a minor axis, two of the radiused surfaces are cutting surfaces, another two of the radiused surfaces are side surfaces, each of the side  
25 surfaces has a first radius of curvature, each of the cutting surfaces has a second radius of curvature smaller than the first radius of curvature, and twice the second radius of curvature is less than one third as long as the minor axis.

61. The blade of claim 32, wherein the blade has two main surfaces, two angled surfaces which intersect at the working edge, and two non-working edges, one of the non-working edges between each of the angled surfaces and one of the main surfaces, and  
5 wherein the blade has a cross-section in a plane perpendicular to the longitudinal axis, the cross-section determines a planar surface that is normal to the main surfaces and to the plane, and each plane  
10 between the working edge one of the non-working edges is oriented at an edge angle of at least 50 degrees with respect to the planar surface.

62. The blade of claim 61, wherein each of the angled surfaces is flat.

15 63. The blade of claim 61, wherein each of the angled surfaces is convex.

64. The blade of claim 61, wherein each of the angled surfaces is concave.

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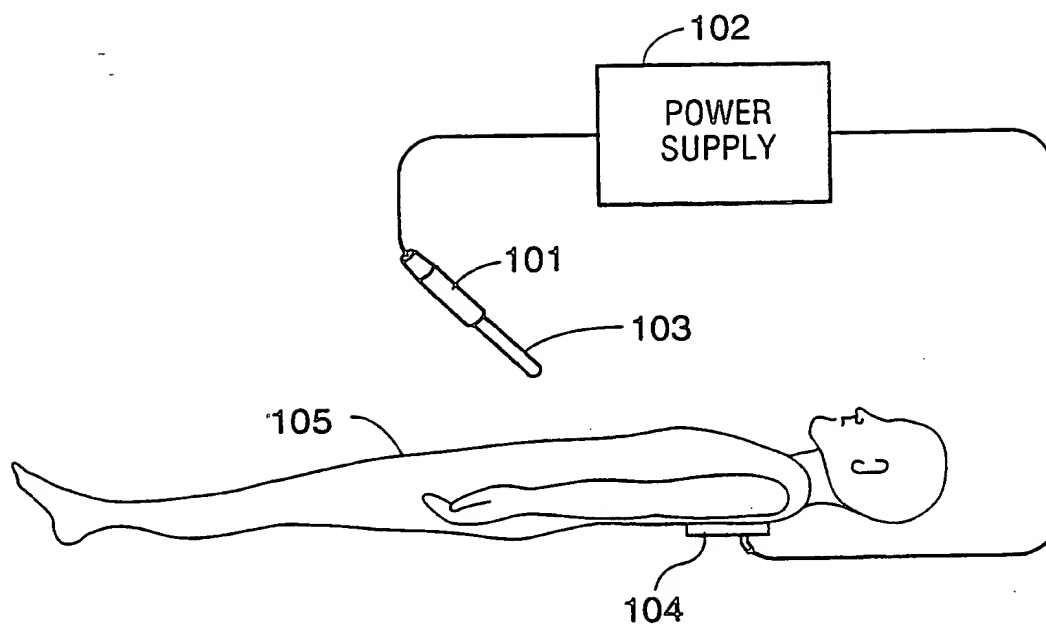


FIG. 1

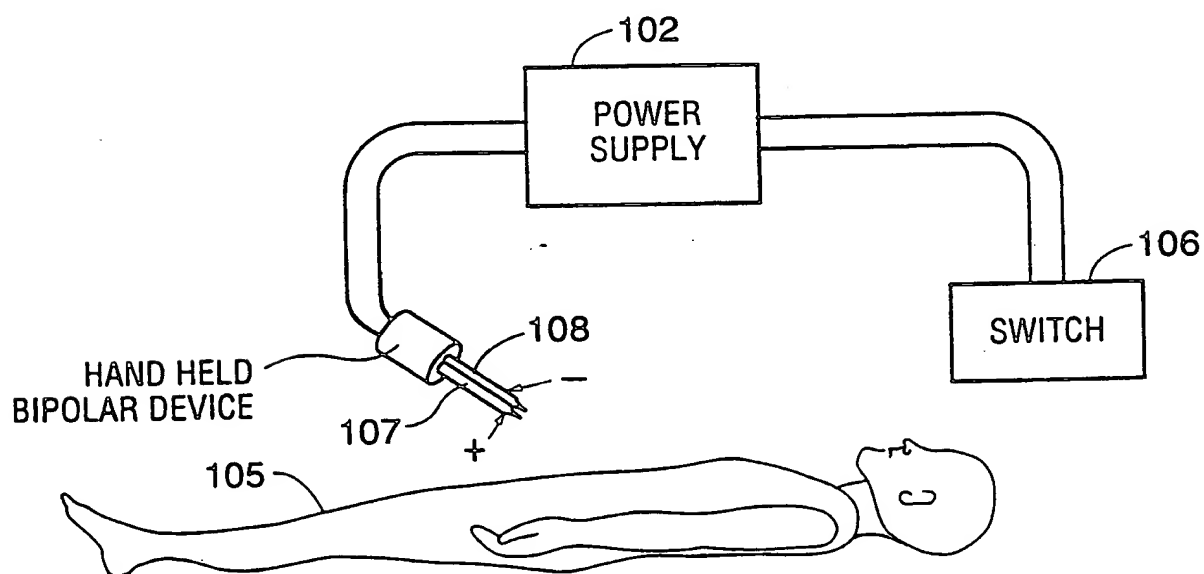


FIG. 2

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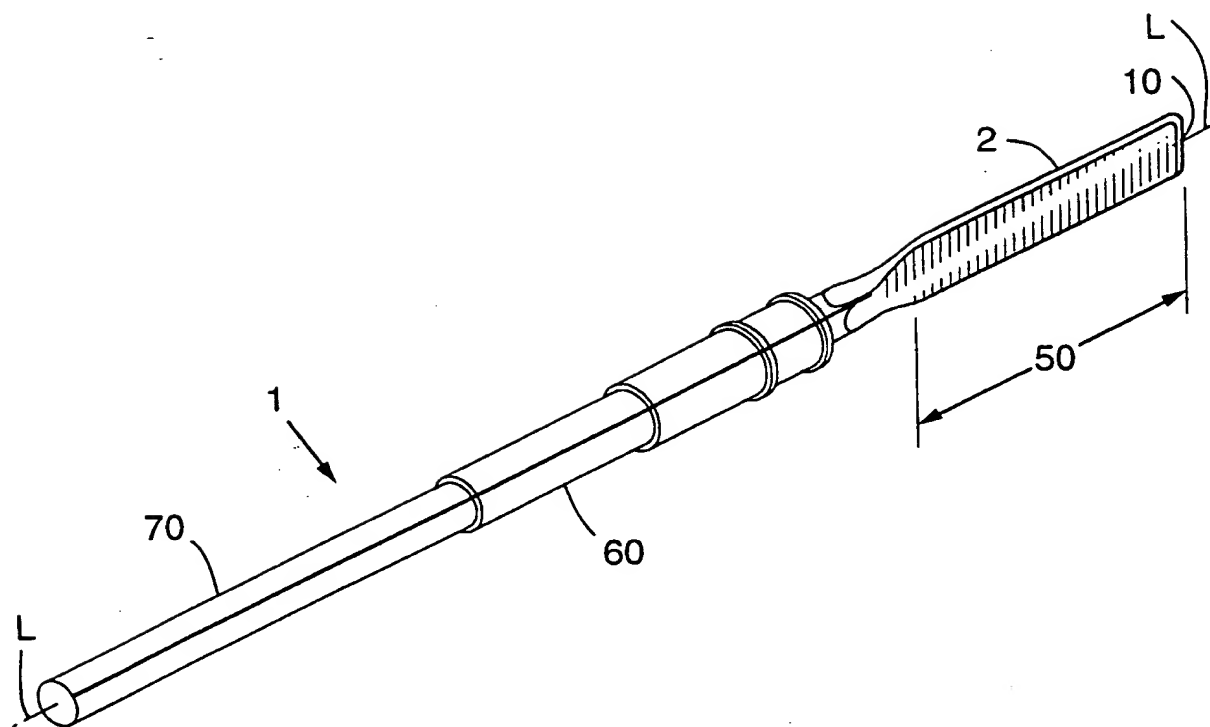


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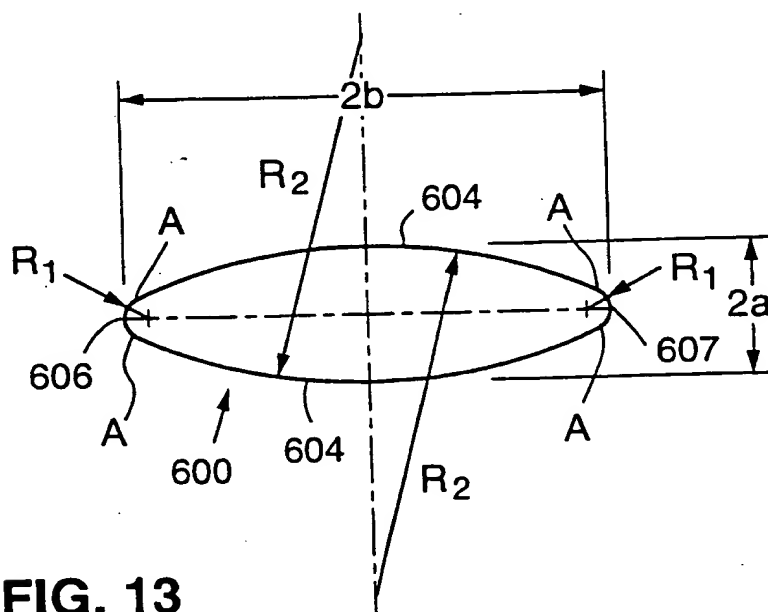


FIG. 13

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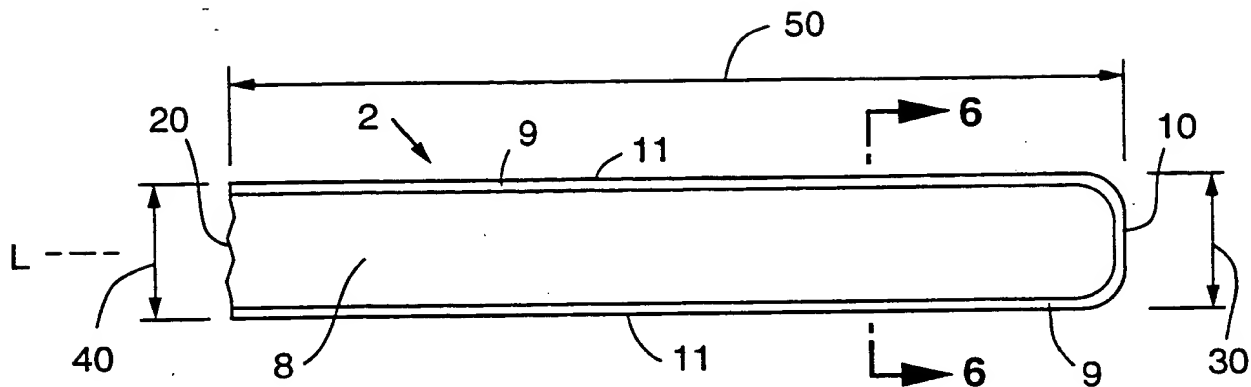


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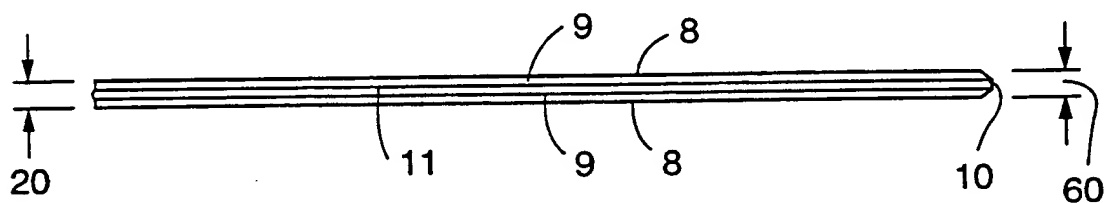


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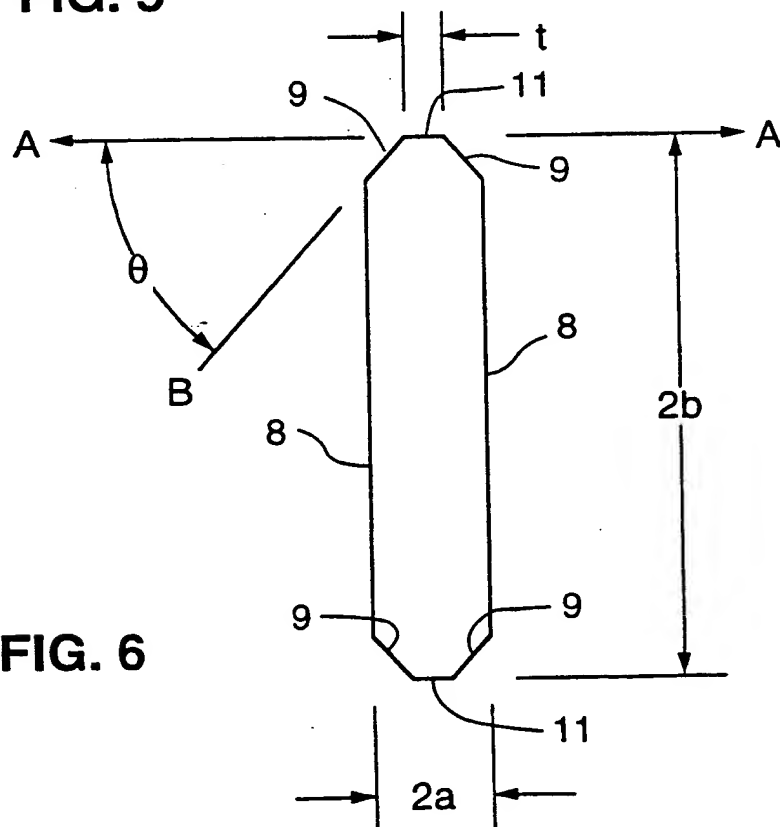
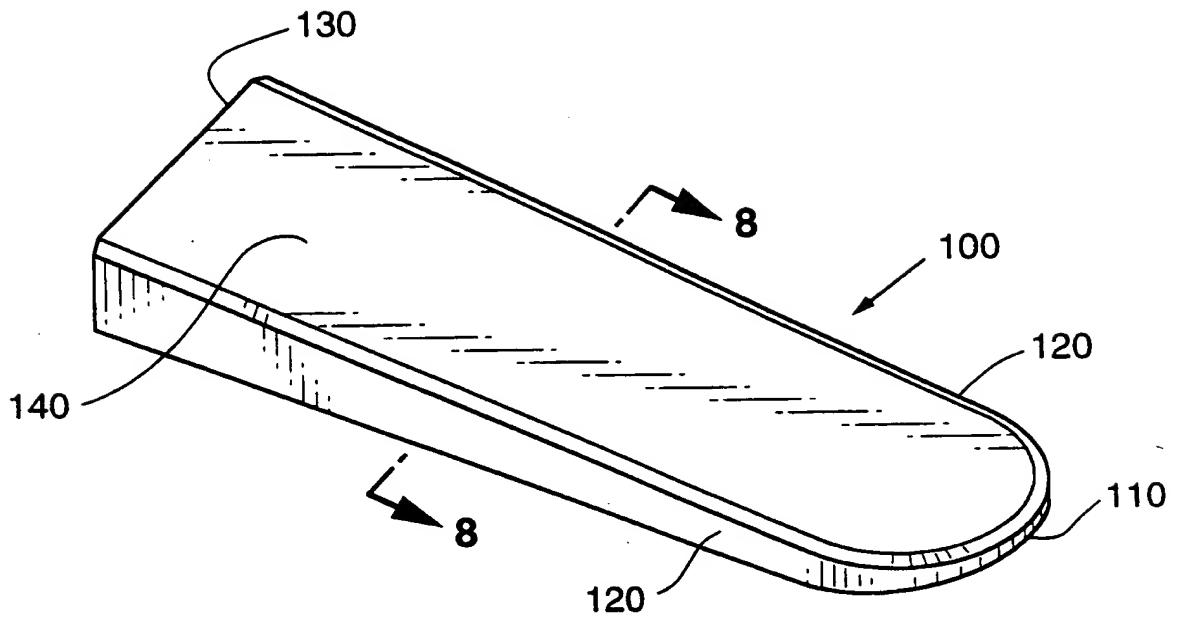
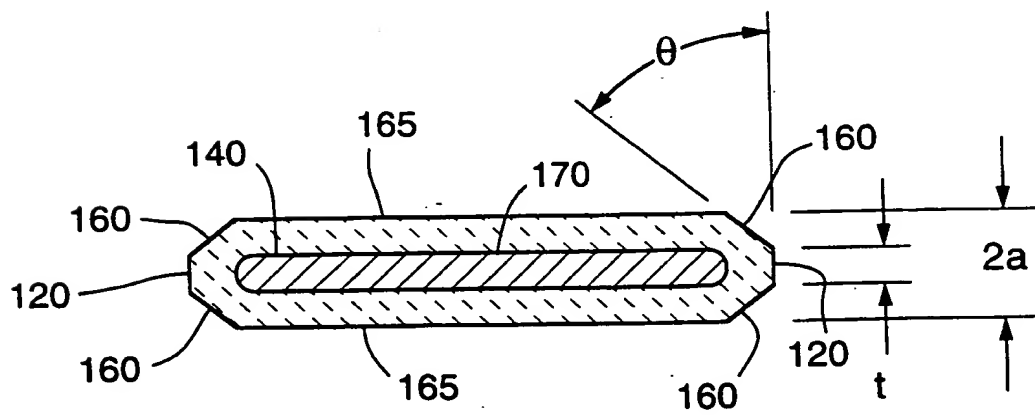


FIG. 6

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**FIG. 7**



**FIG. 8**

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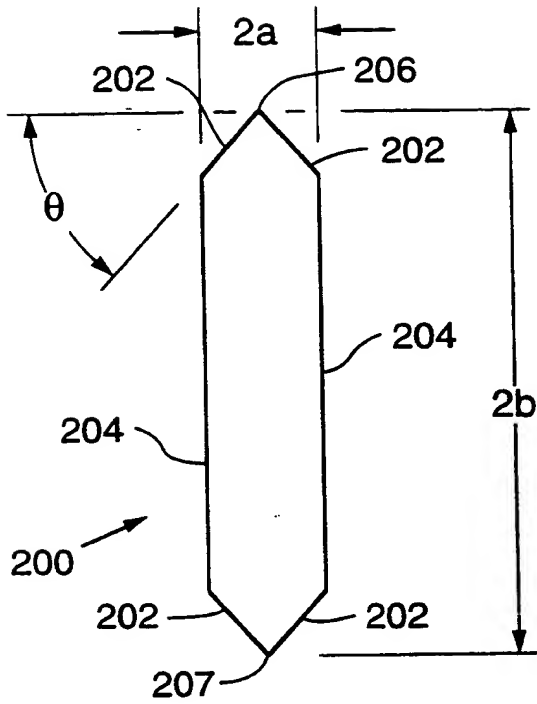


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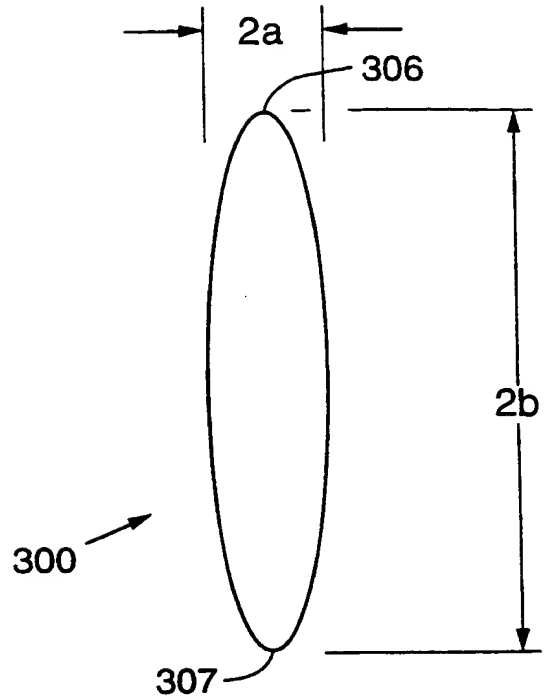


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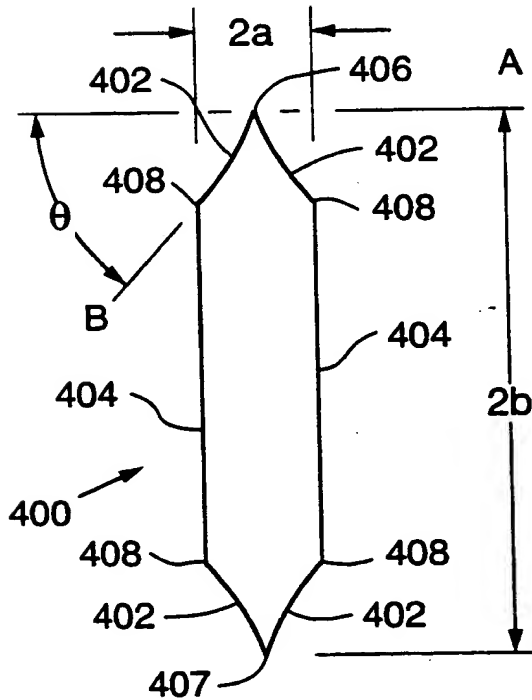


FIG. 11

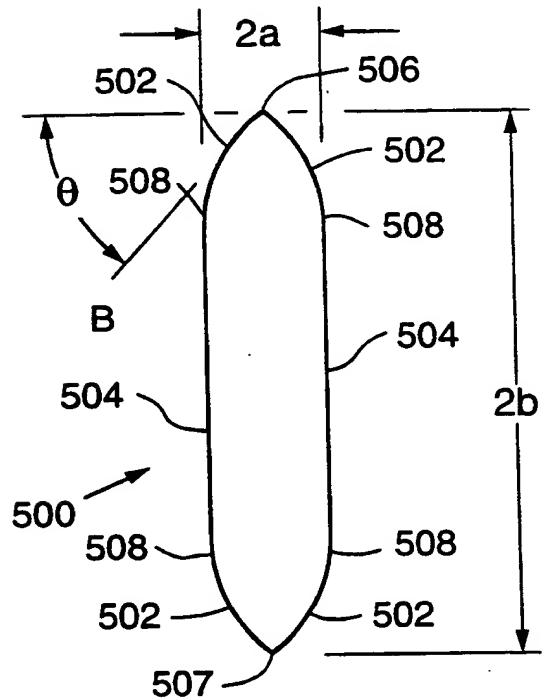


FIG. 12

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US99/03178

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : A61B 17/36

US CL : 606/39, 41, 45-50

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 606/39, 41, 45-50

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	US 3,911,241 A (JARRARD) 07 October 1975, entire document.	1-3, 5, 6, 8, 13, 14, 16, 28, 29, 32-34, 41, 42, 44  4, 7-12, 15, 17- 27, 30, 31, 35-40, 43-63



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
*A* document defining the general state of the art which is not considered to be of particular relevance	*X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Z* document member of the same patent family
*O* document referring to an oral disclosure, use, exhibition or other means	
*P* document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

14 APRIL 1999

Date of mailing of the international search report

26 MAY 1999

Name and mailing address of the ISA/US  
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Facsimile No. (703) 305-3230

Authorized officer

DAVID SHAY

Telephone No. (703) 305-2215

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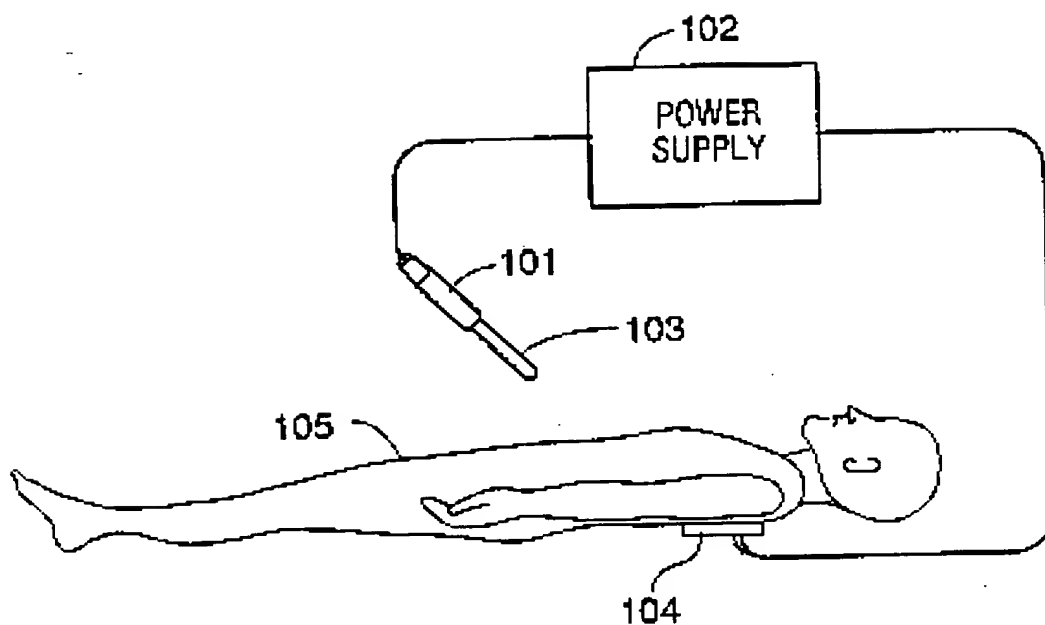


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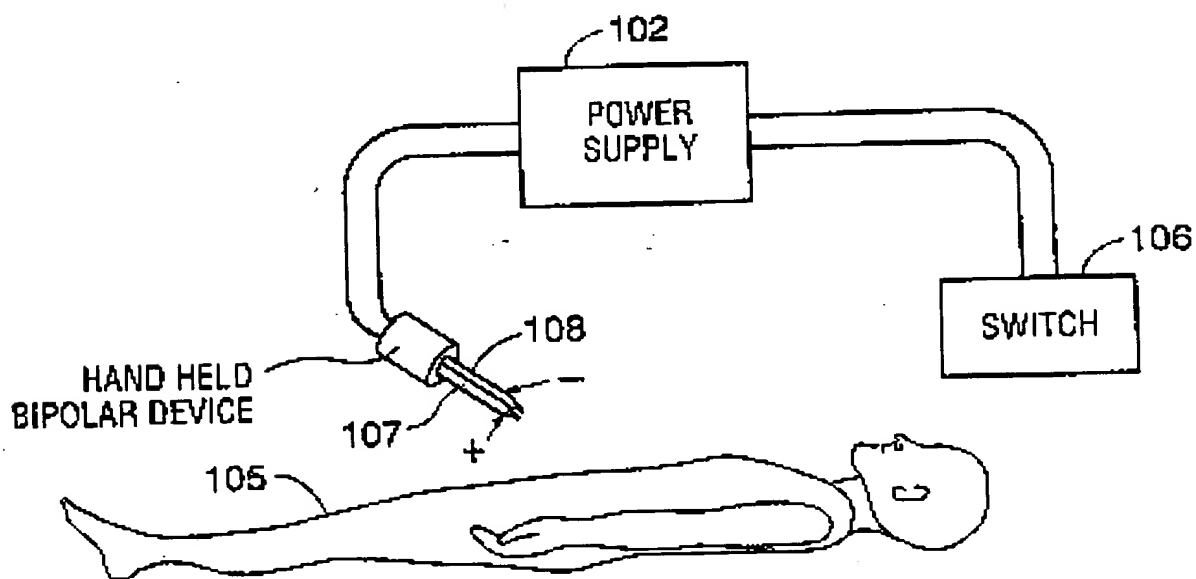


FIG. 2

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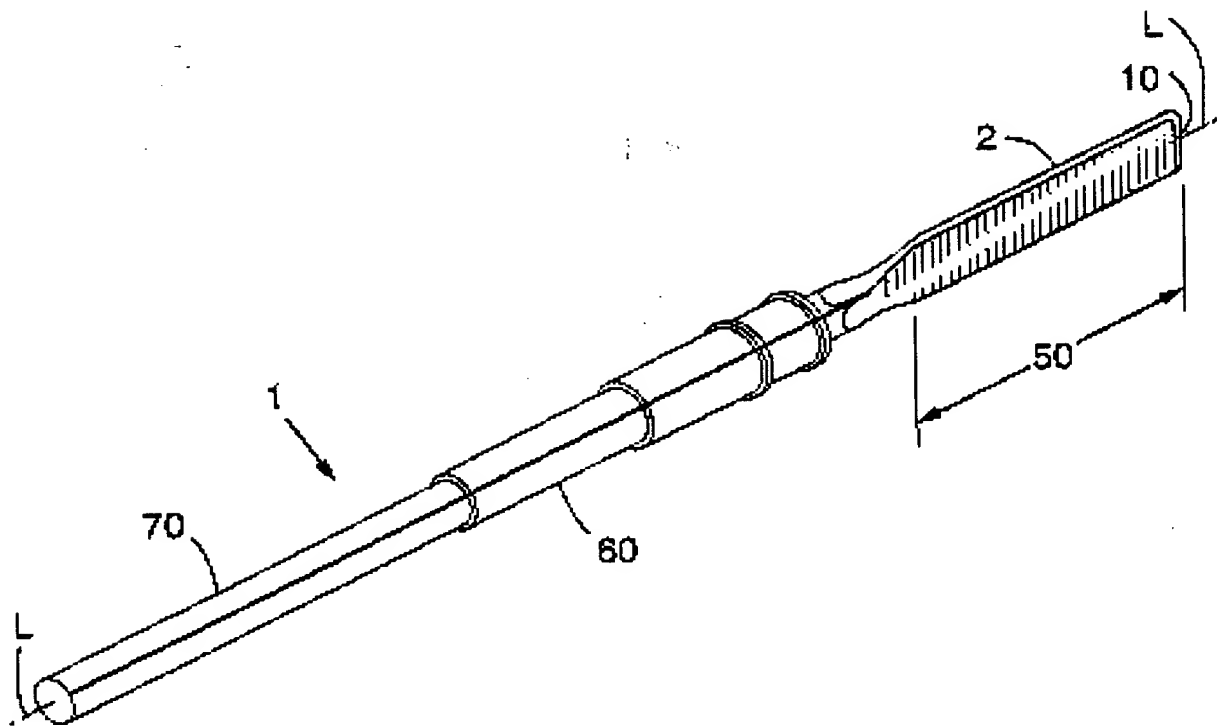


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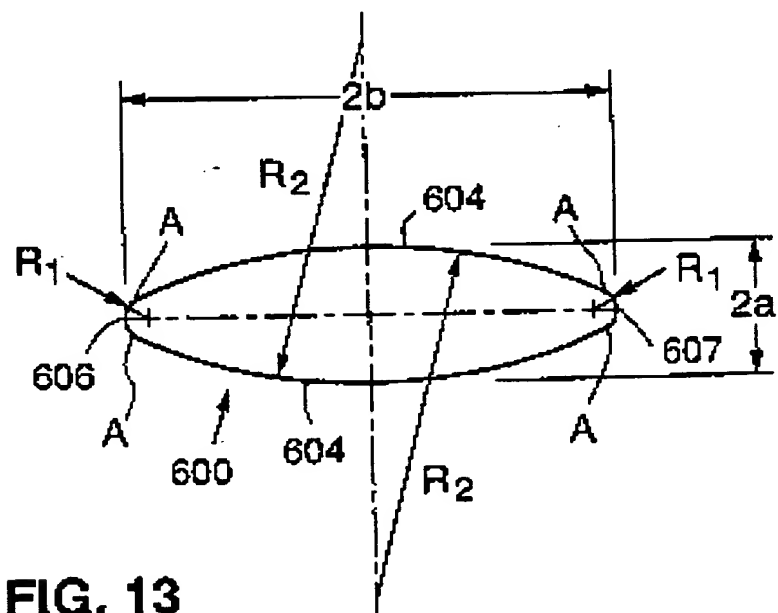


FIG. 13

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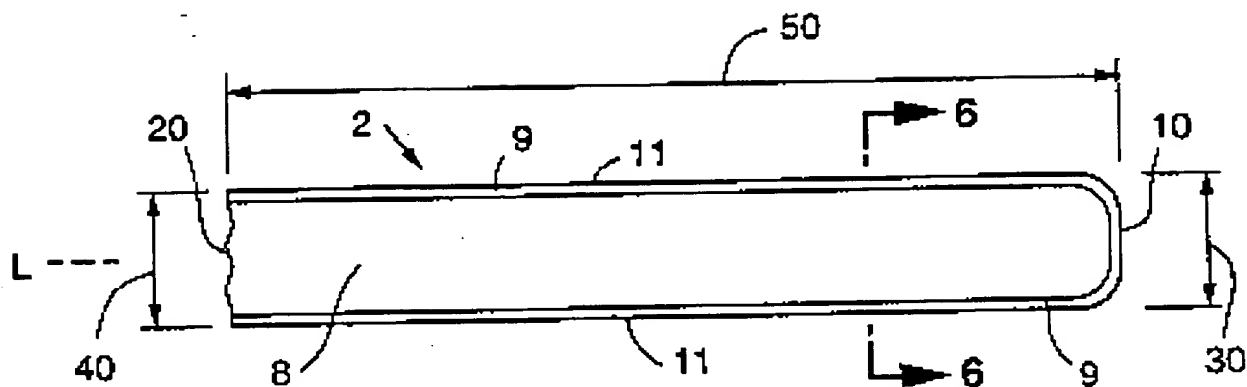


FIG. 4

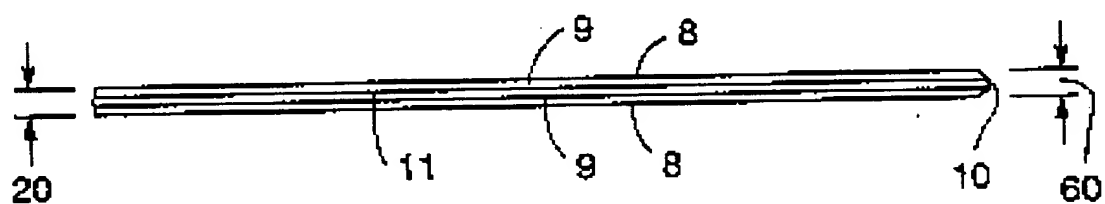


FIG. 5

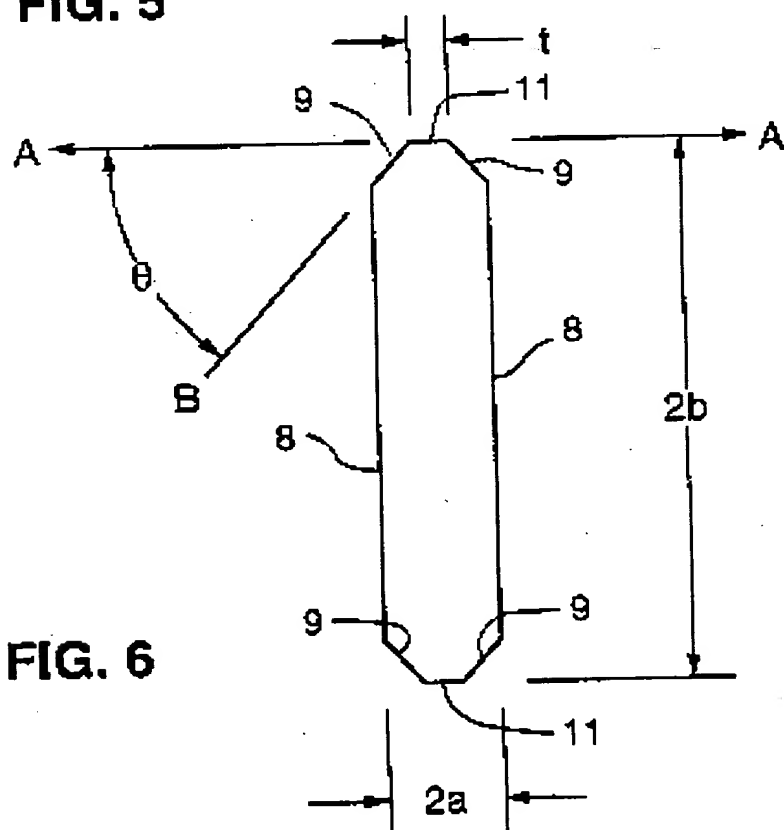


FIG. 6

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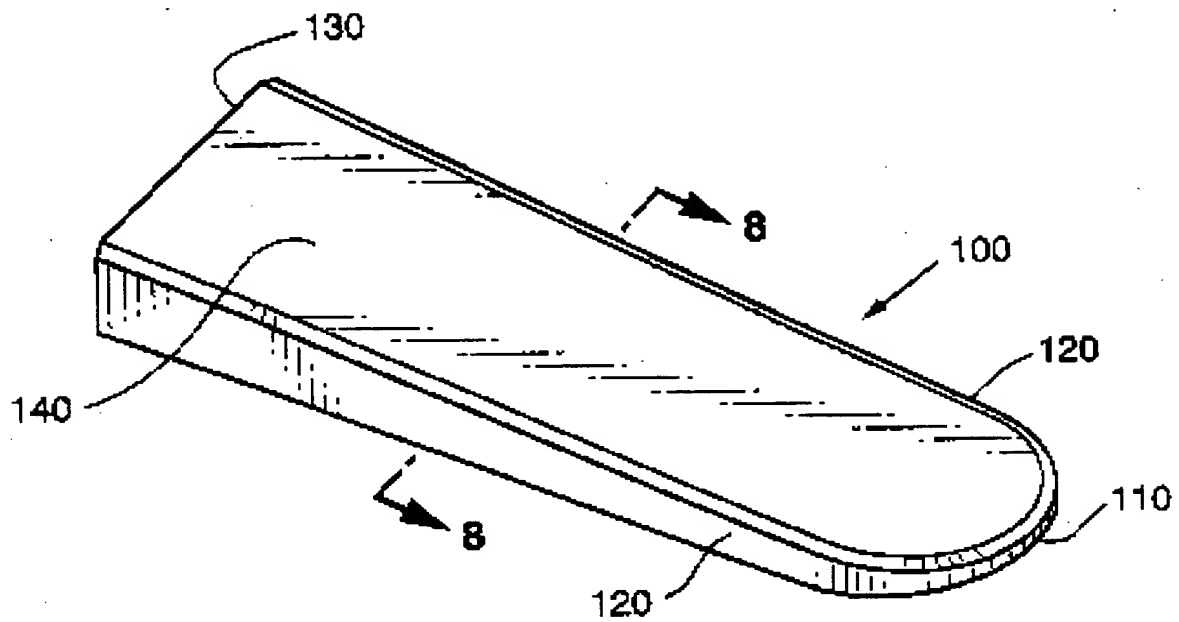


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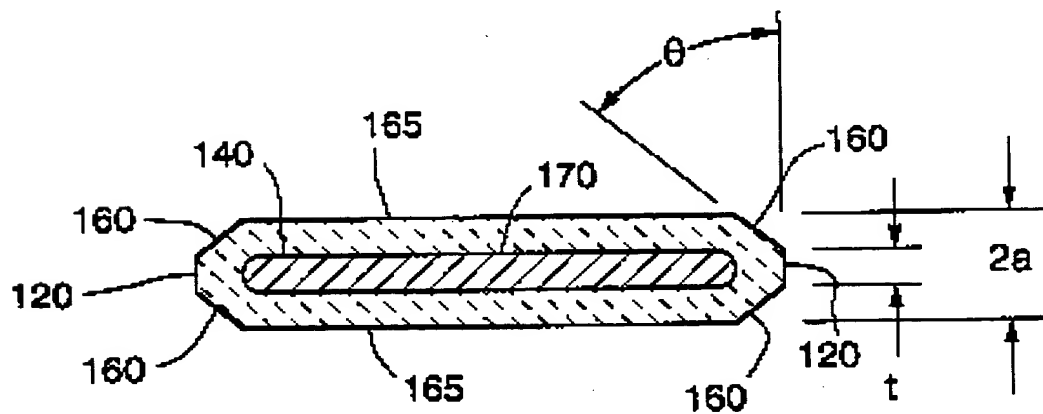


FIG. 8

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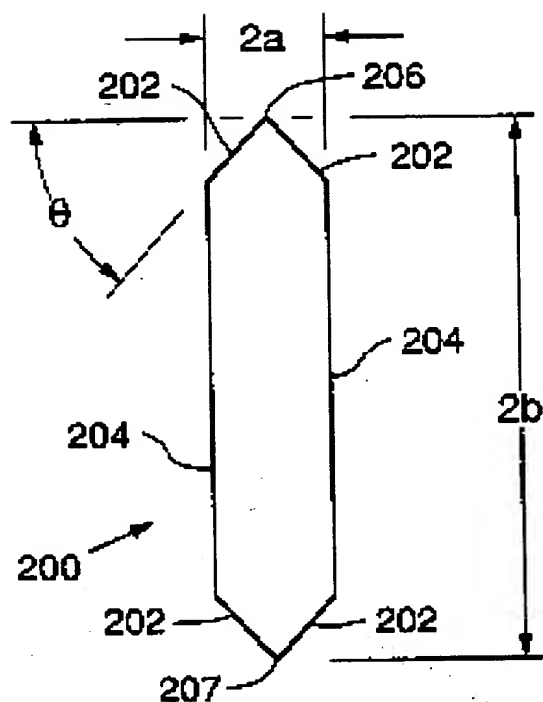


FIG. 9

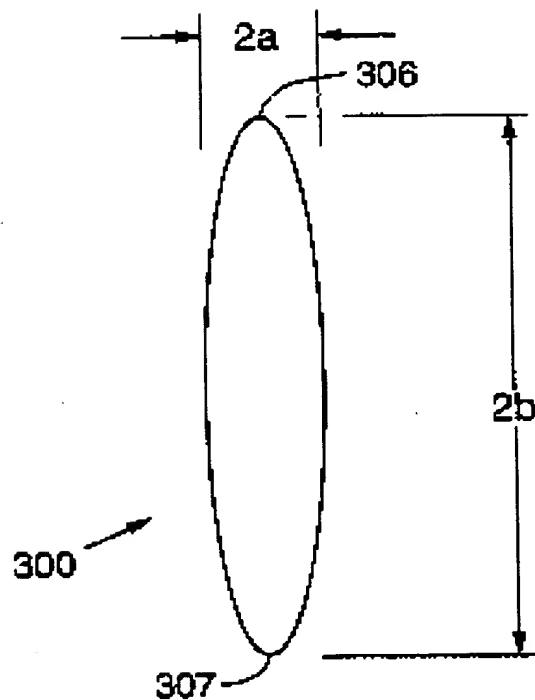


FIG. 10

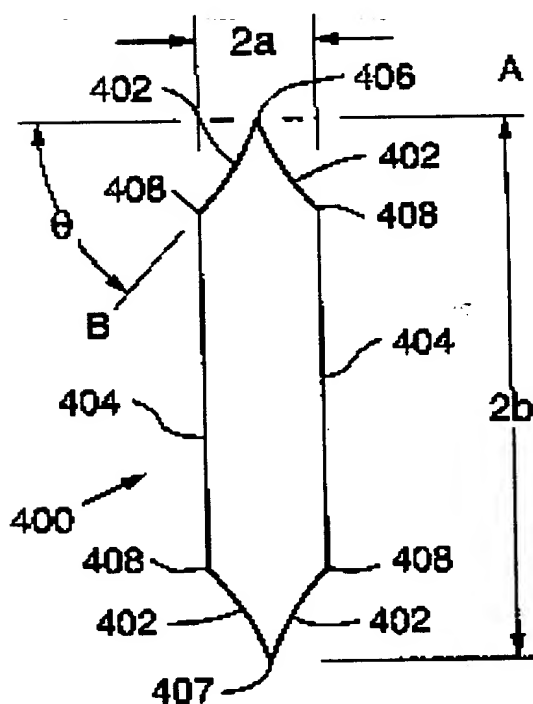


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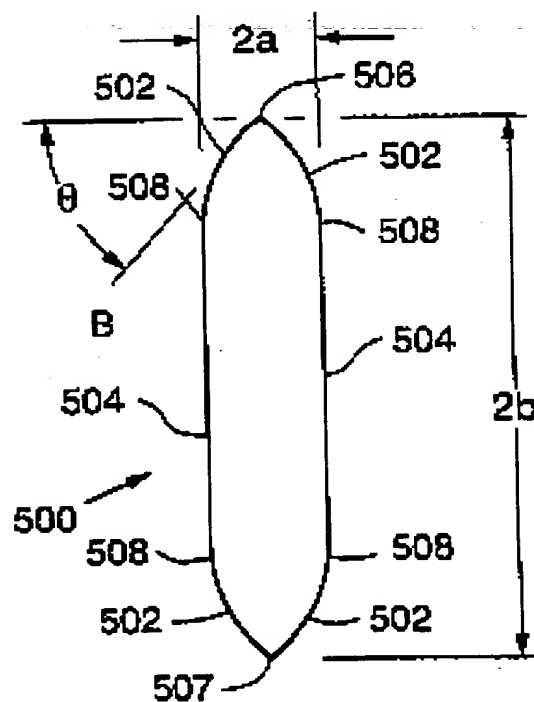


FIG. 12

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